IceCube-Gen2

Albrecht Karle (University of Wisconsin-Madison)

P5 Town Hall, March 23, 2023

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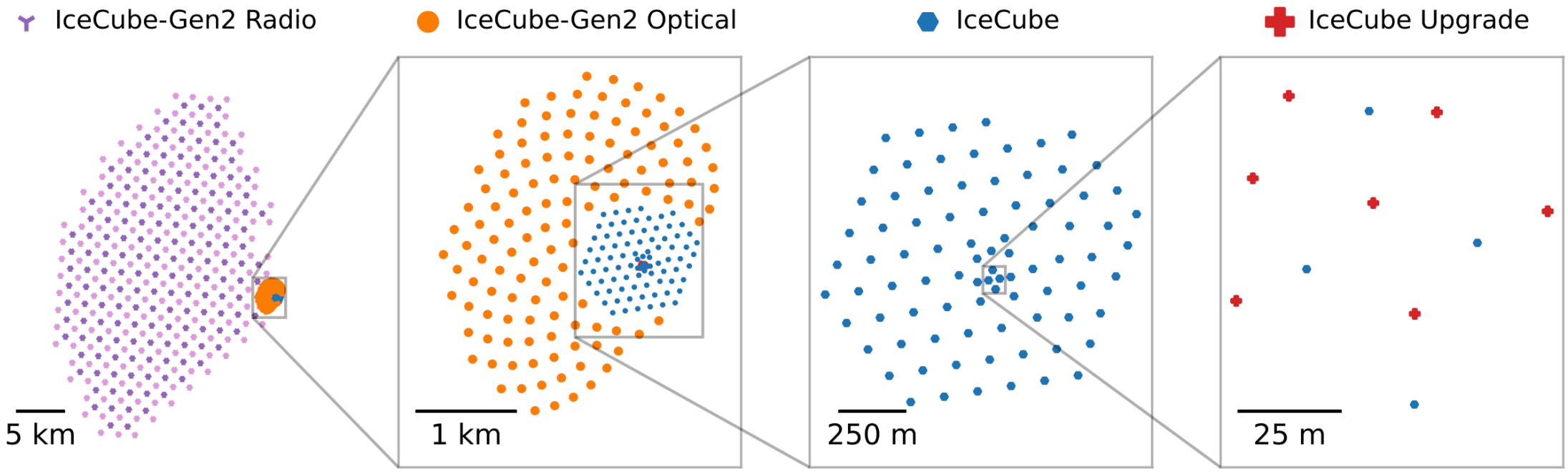
IceCube-Gen2: A wide-band observatory

Optimizing scales for leading sensitivity from 10^9 to 10^{20} eV



>30 PeV

> 3 TeV

>0.5 TeV

competed in 2011

> GeV

under construction,
deployment in Dec. 2025

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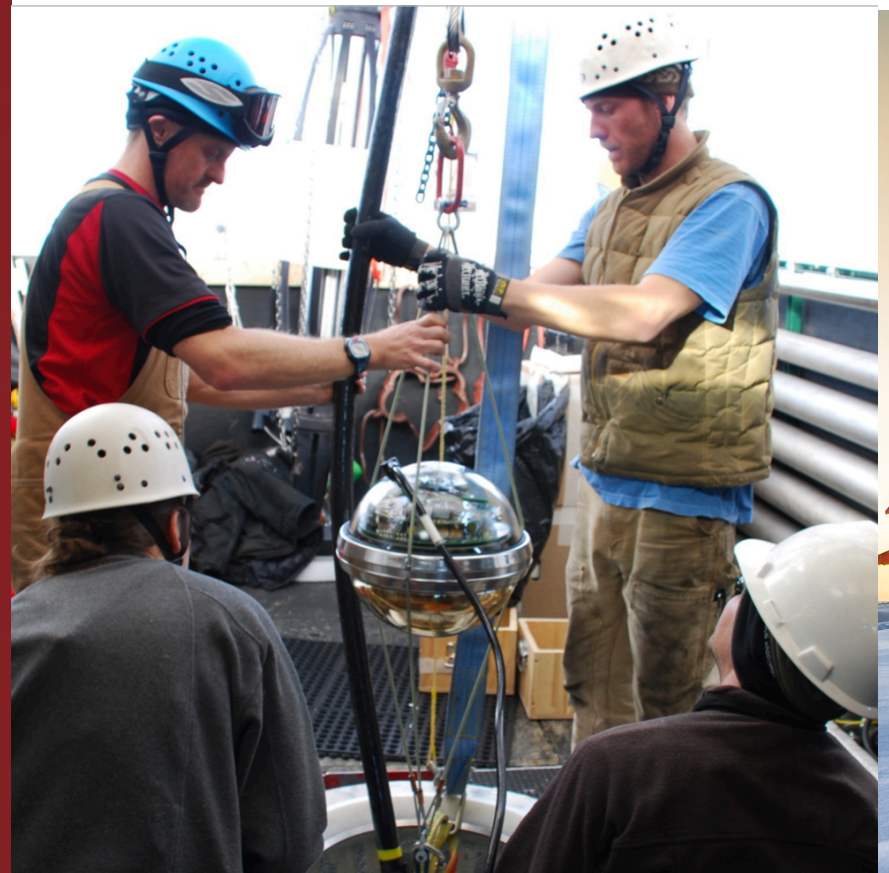
The foundation: IceCube is running very well

Optical sensors are extremely stable

Only 6 sensors were lost out of 5000
in the last 10 years.
Uptime averages 99% for the past 10 years.

→ Can run IceCube for many years as an integral part of IceCube-Gen2.



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IceCube-Upgrade

In progress

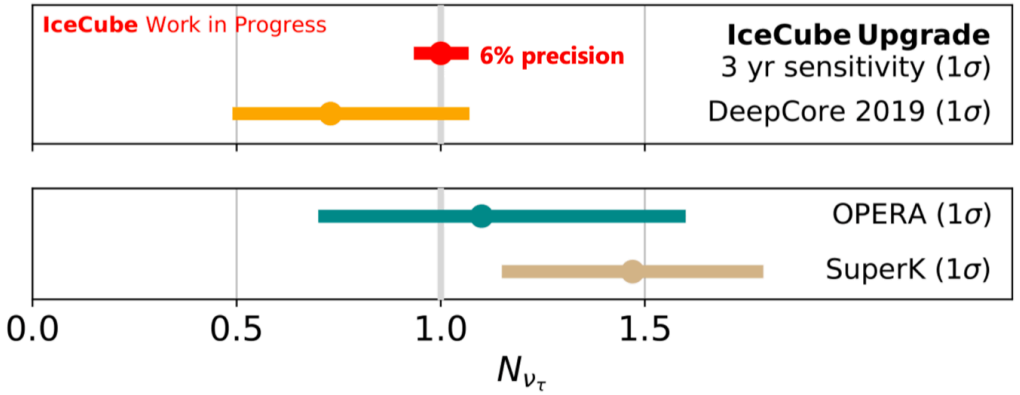
Scope:
Add 7 new strings, 700 sensors, densely packed in the center of IceCube.

Instrumented volume: 2 Mt
Energy threshold: ~ 1 GeV

Science goals:
- Fundamental neutrino properties
- Improved calibration
- R&D, new instruments.

Project rebaselined after Covid delay.
Final installation: 2025/26 Pole season.

Science example:
Atmospheric tau neutrino appearance



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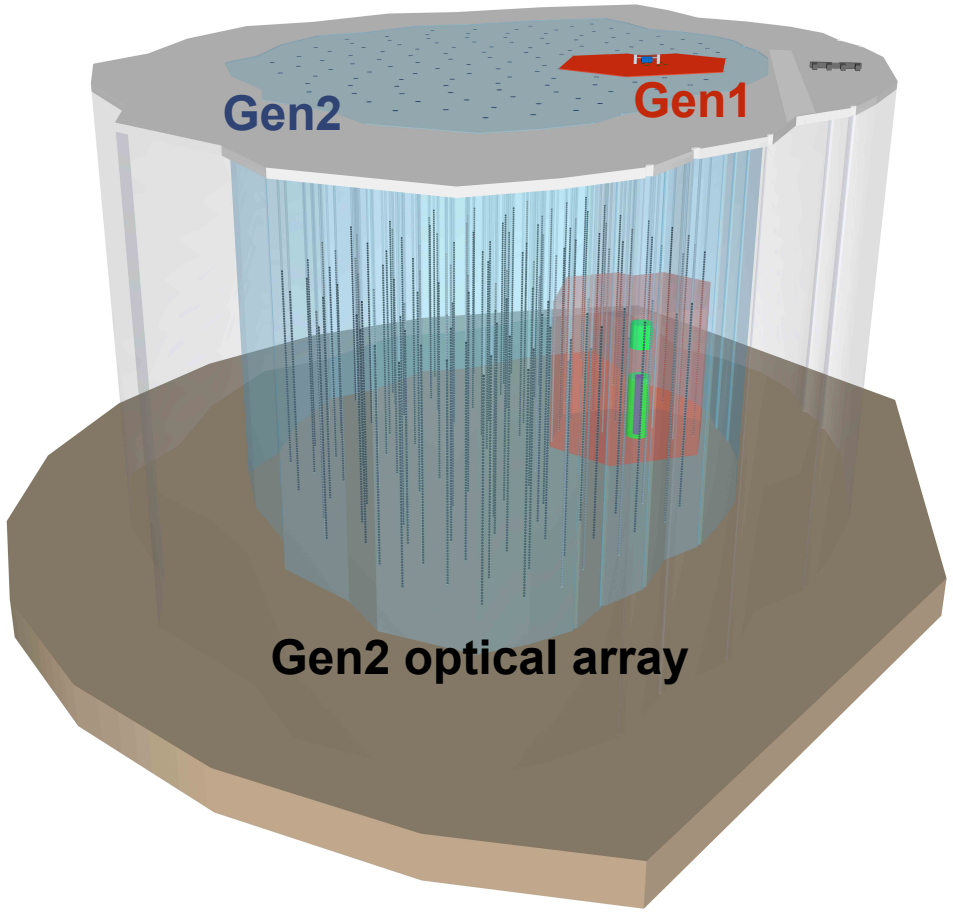
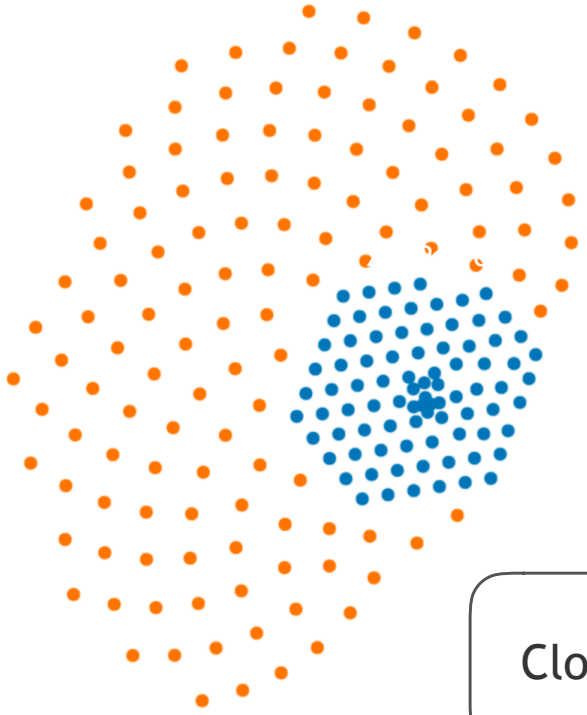
Scope: 1. The Optical Cherenkov Array

The main detector component.



Instrumented Volume: 8 km^3

9600 optical sensors on
120 strings



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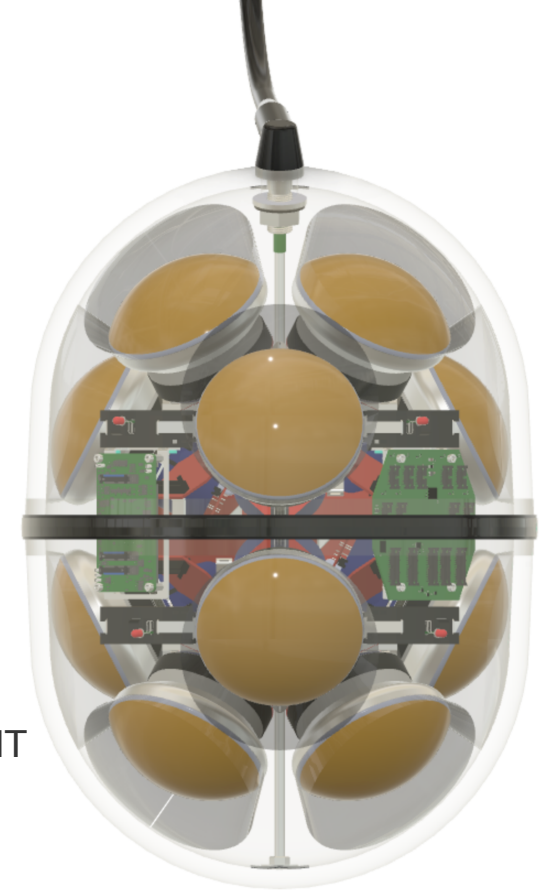
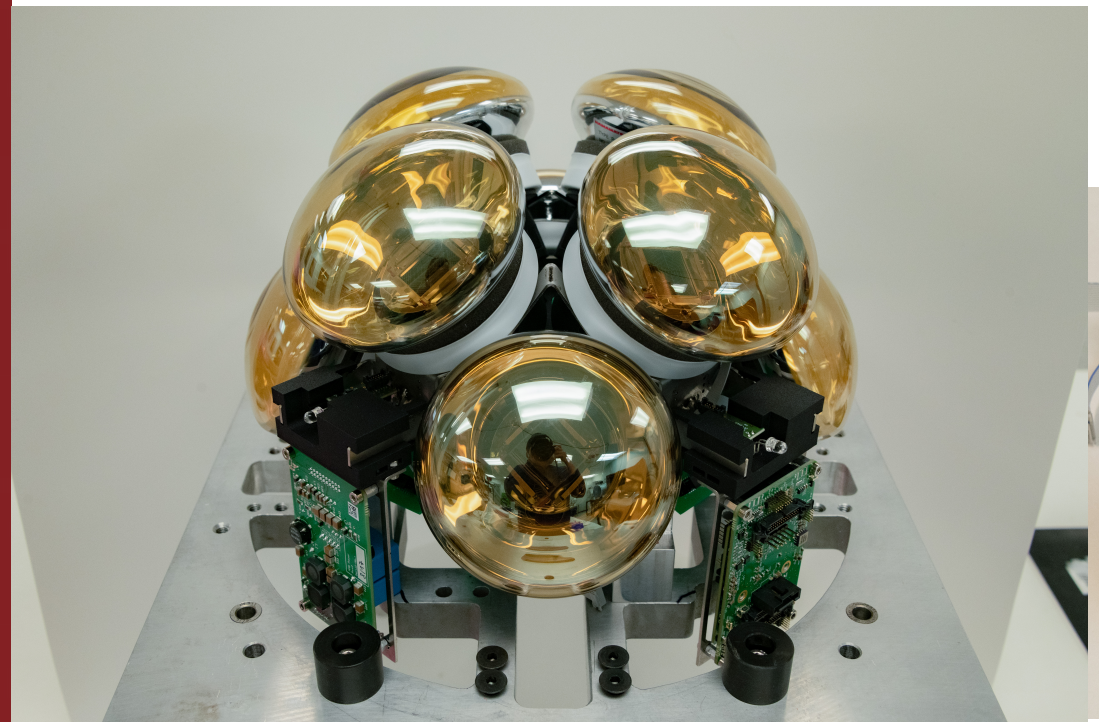
Sensor and Electronics

- **4-inch PMTs developed for IceCube-Gen2**
- **>3 x sensitivity**
- **>100 times dynamic range**
- **Less power**
- **Cost per photoelectron: <1/2 IceCube**



16 or 18 x 4 inch PMT
Diameter: 31 cm



160,000 PMT

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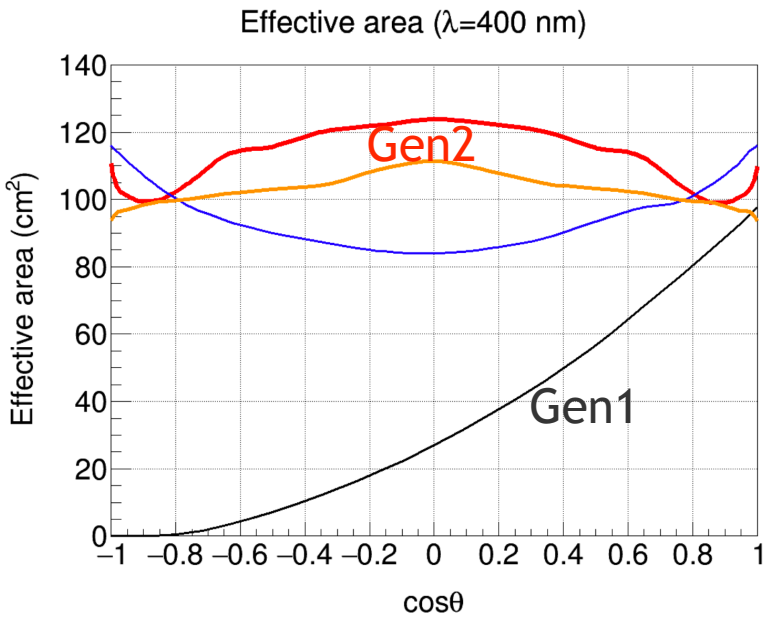
Higher Sensor sensitivity —> Larger Muon Effective Area

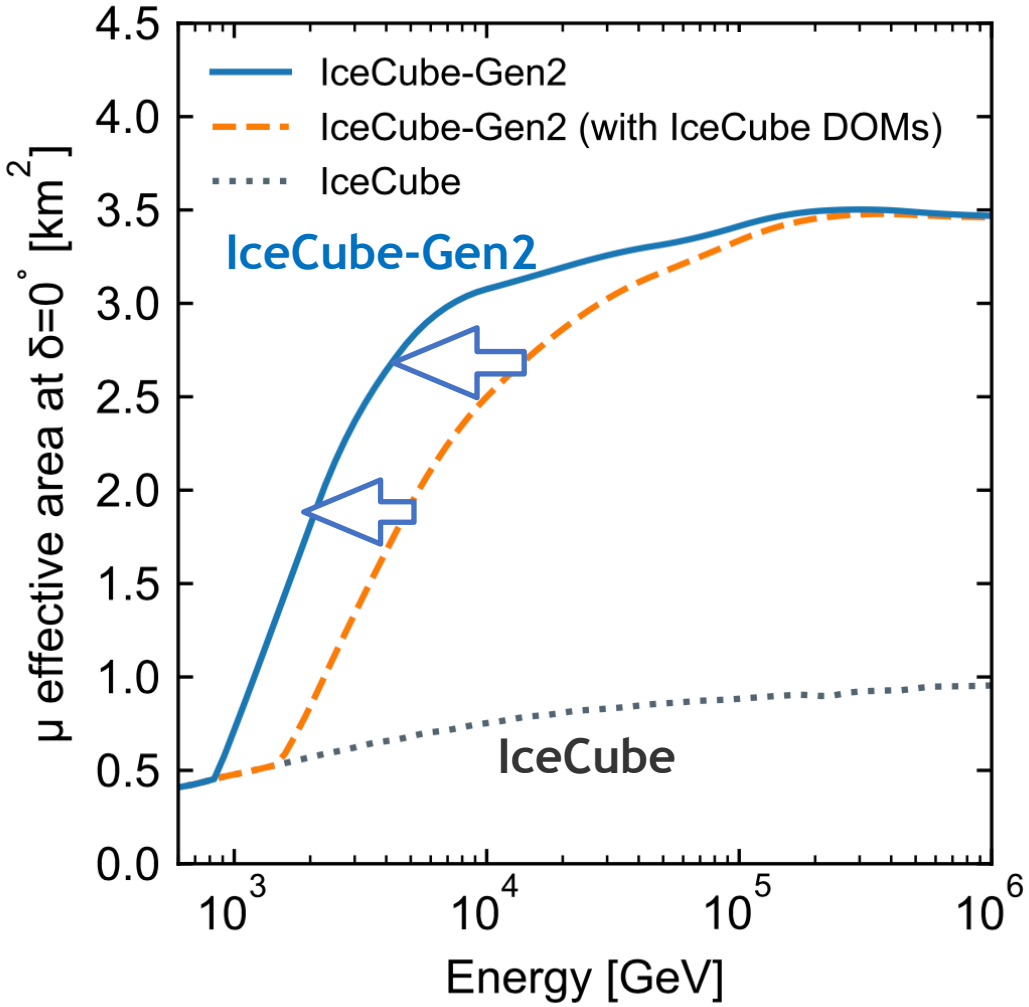
Factor 3 more photons detected

—>

- Lower energy threshold

- Angular resolution: 0.1 - 0.3°





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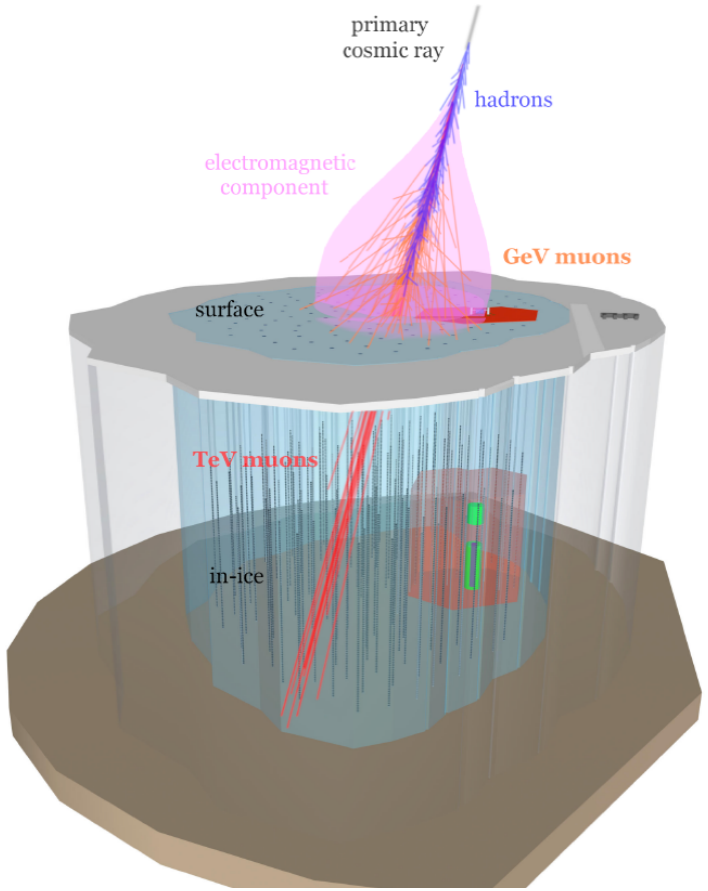
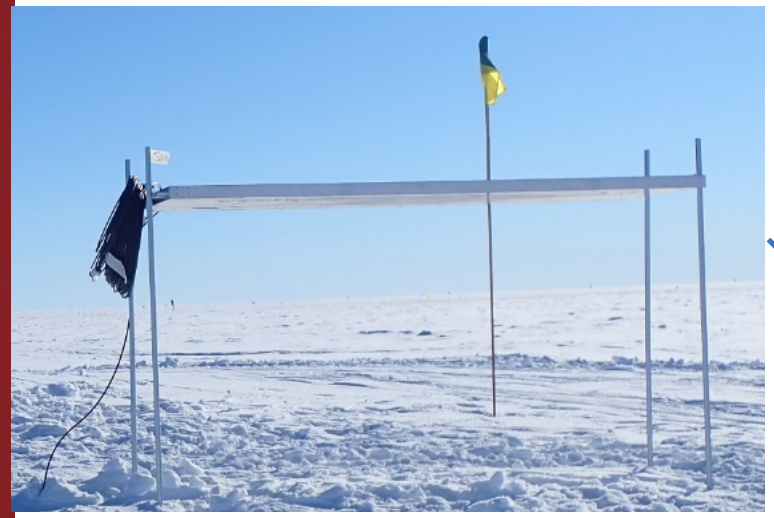
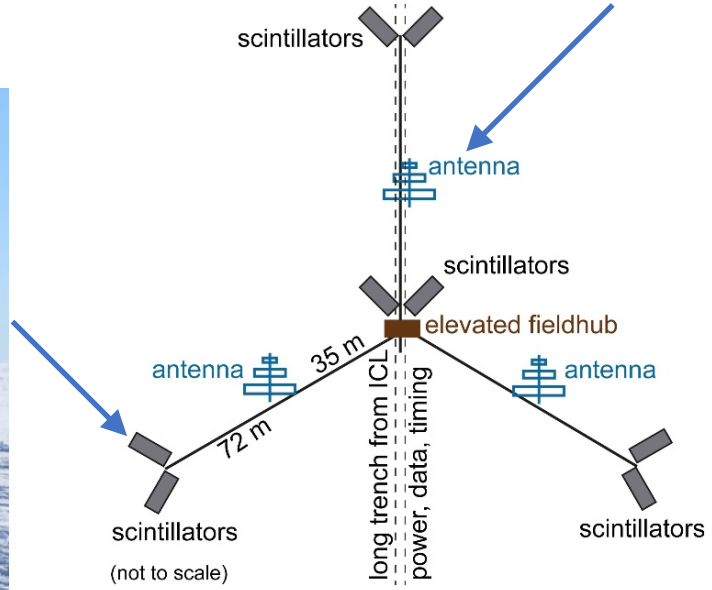
Scope: 2. The Surface Array

- Veto for larger and purer sample of PeV neutrino candidates
- High accuracy for cosmic rays in the PeV to EeV region
  - particle physics in air showers
  - cosmic-ray astrophysics







Reference design of Surface Array:

one station per optical string (120)

- 4 pairs of scintillators enabling low threshold for veto
- 3 radio antennas increasing accuracy at high energies

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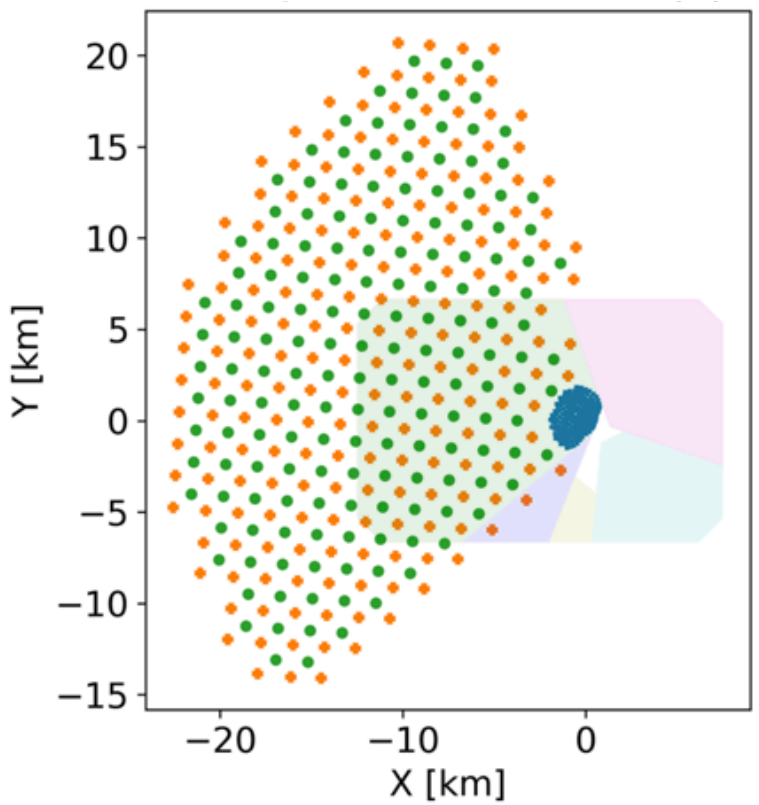
Scope: 3. The Gen2 radio array

Energy range from 30 PeV to well beyond EeV



361 stations

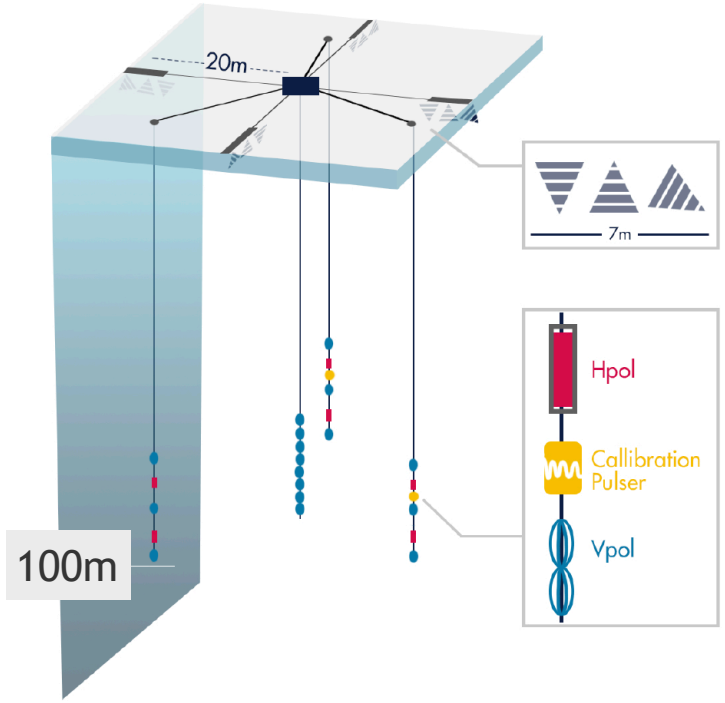
Area: 500 km²

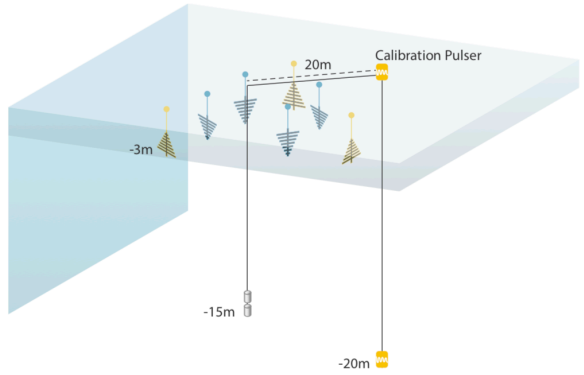
Ice target: 1000 km³

The phased array trigger was successfully tested in ARA, is now used in RNO-G.

RNO-G:

- Currently in construction in Greenland
- 28 stations, 7 deployed (10% of Gen2)
- Serves as prototype array for Gen2.





—> short presentations
Stephanie Wissel
Cosmin Deaconu
Kaeli Hughes

Heritage: RICE, ANITA (Antarctica from balloon), ARA (South Pole), ARIANNA (Antarctica), RNO-G (Greenland)

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Logistical Support

1. Logistical Support provided by **NSF's Office of Polar Programs made IceCube possible**.
2. IceCube Gen1: 9.5 million lb of cargo + fuel, 300 LC 130 missions. Construction occurred simultaneously with the South Pole station completion and South Pole Telescope construction.
3. Logistical Support **requirements are well understood**.
4. **Strategies for logistical support exist**.
    1. Population of 60 people: → Temporary lodging summer camp.
    2. Cargo: Overland traverse is scalable (and lower cost than air transport).
5. All logistical **support will be on project budget. Successful logistics will require high-level prioritization and strategic planning at NSF's Polar Program**.

C17 transport (J. Donnenfeld)

Amundson Scott South Pole station

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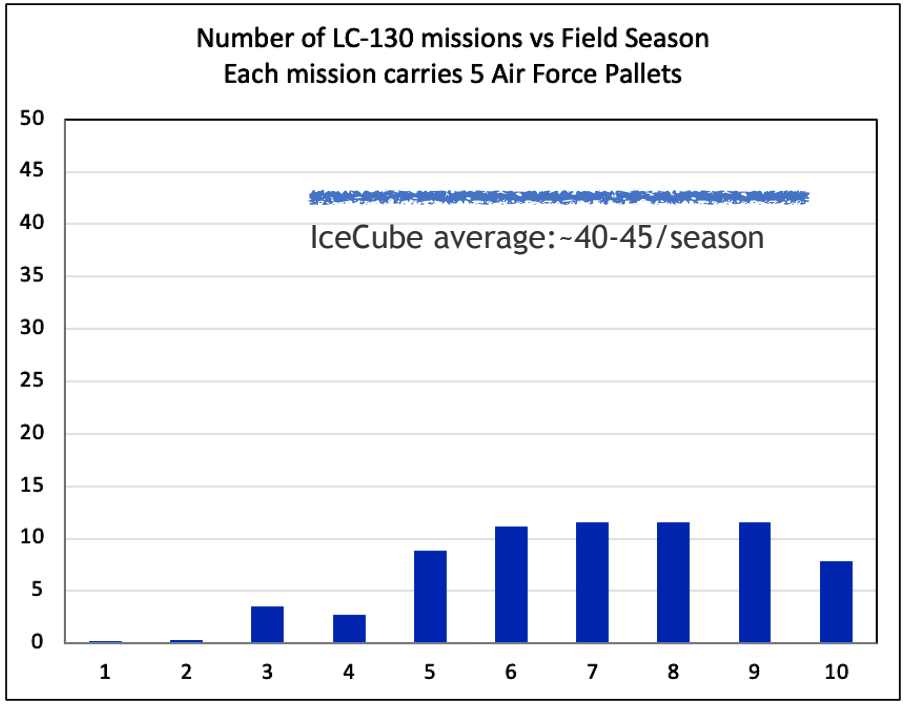
Logistical Support Example: LC-130 flights

LC 130 aircraft



Overland traverse

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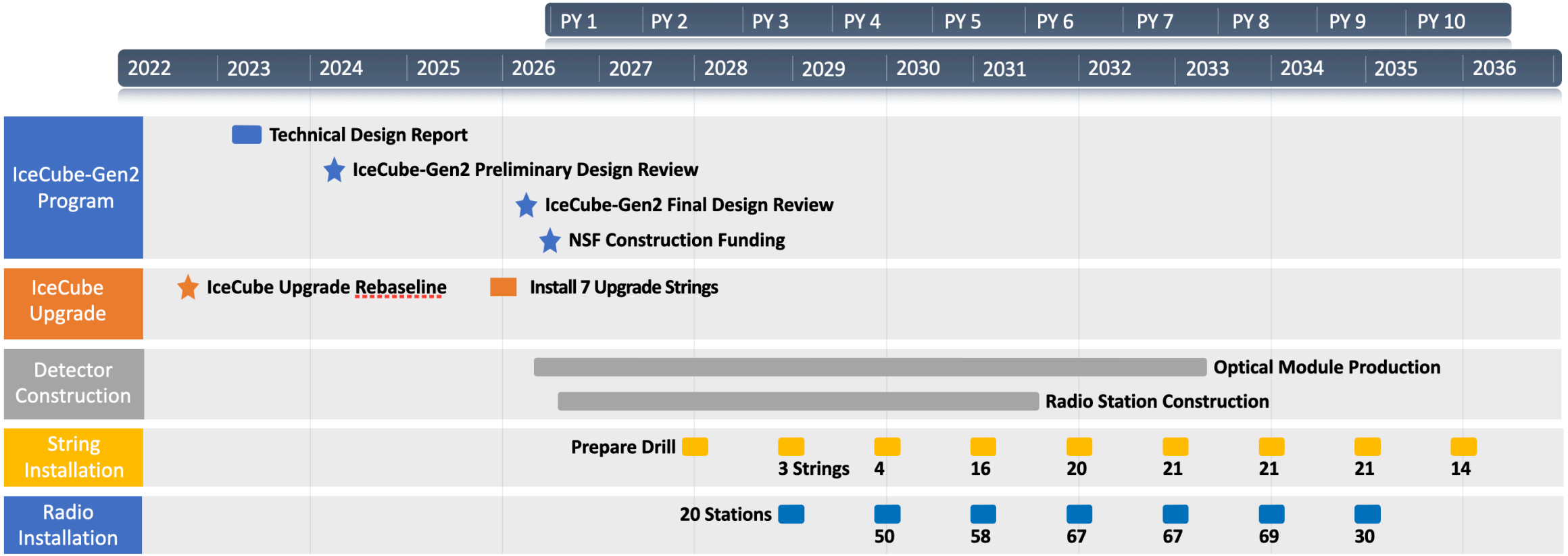
Schedule (Technically Driven)



Technically Driven Schedule: These are the dates the Project would be ready to move through the MREFC process

- Preliminary Design Review in 2024, Final Design Review and Construction Funding Start in 2026

Project Year: Project Year starts with Construction Funding Start

— in our schedule this could be as early as June, 2026

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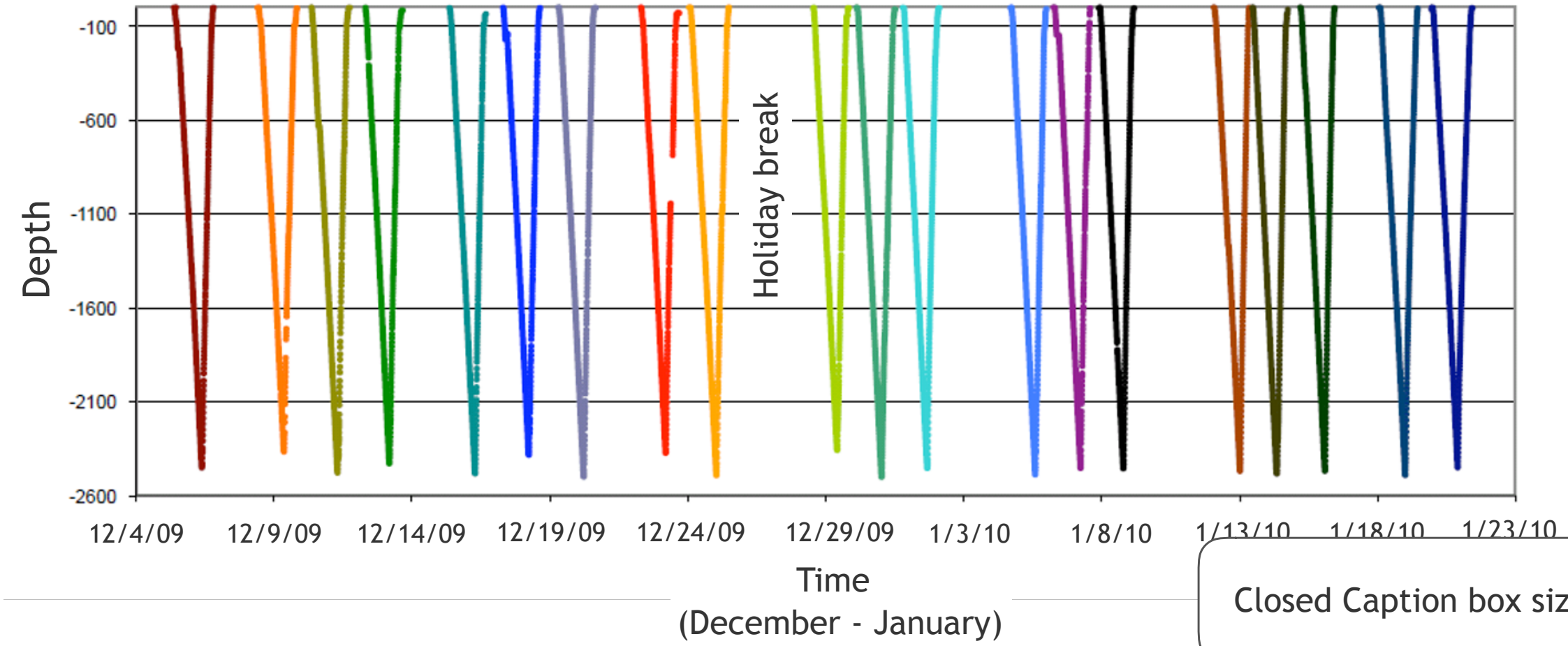
Drilling in IceCube: 2009/10 season

Drilling drives the critical path for construction.

The field season is limited (Nov 15 to Feb 15). In this season, 20 holes were drilled in 50 days.
Gen2: 120 strings.



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Cost

Total Project Cost*: $407.9M
In-Kind:$69.0M
NSF: $338.9M (~35 to 40M$/yr)

L2	Task	Total cost	In-Kind	NSF
1.1	Project Office	28.1	.0	28.1
1.2	Implementation	61.6	.0	61.6
1.3	Instrumentation - Deep	151.9	64.0	87.9
1.4	Instrumentation - Radio	25.9	5.0	20.9
1.5	Data Systems	13.1	.0	13.1
1.6	Commissioning and Calibration	12.2	.0	12.2
1.7	ASC Coordination / Polar Support	53.9	.0	53.9
Total w/o contingency		346.8	69.0	**277.8**
Contingency (22%)		61.1		61.1
Total with contingency		407.9	69.0	**338.9**

Ref.: Astro 2020, latest bottoms-up cost estimate, 12/2019

Cost Drivers:

—> Instrumentation: 9,600 Optical modules
—> Construction at the Pole (Drilling)
—> Antarctic Logistics Support.

Astro2020: “The TRACE cost estimate is 20 percent higher than the project-estimated cost, which the panel considers only a minor concern.”

In-kind contributions Non-US:

- ~70M$ (90% in instrumentation, capital equipment)
- ~1/2 of all detector hardware

New knowledge:

- Savings on Cables (new technology), DOMs robust
- On track to secure a second vendor for PMT (risk, cost)
- Upgrade: Collaboration and labs are ramping up on construction
- Inflation

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Cost profile (Astro2020)

Cost Profile - US [Real Year, M$]												
		Project Year										
L2	Task	PY01	PY02	PY03	PY04	PY05	PY06	PY07	PY08	PY09	PY10	TOTAL
1.1	Project Office	2.83	2.89	2.95	3.01	3.08	2.73	2.66	2.72	2.77	2.45	**28.08**
1.2	Implementation	21.68	5.09	4.25	4.34	4.57	4.61	4.27	4.35	4.44	4.06	**61.64**
1.3	Instrumentation - Deep	6.28	6.84	9.38	14.70	16.45	16.59	12.35	5.32			**87.91**
1.4	Instrumentation - Radio	1.51	1.93	2.67	2.69	3.11	2.73	2.83	2.14	.66	.68	**20.92**
1.5	Data Systems	1.27	1.03	1.06	1.37	1.44	1.28	1.35	1.36	1.43	1.51	**13.10**
1.6	Commissioning and Calibration	1.13	1.15	1.18	1.20	.99	1.26	1.28	1.31	1.34	1.37	**12.22**
1.7	ASC Coordination / Polar Support	.91	7.98	10.70	8.33	7.70	7.55	3.82	3.31	2.74	.91	**53.94**
	Total development											
	Total US w/o contingency	**35.59**	**26.90**	**32.19**	**35.64**	**37.32**	**36.74**	**28.57**	**20.50**	**13.38**	**10.98**	**277.81**
	Contingency (22%)											**61.12**

Assumed in-kind contributions: $69 M

Cost profile driven by initial investment in drilling and then ongoing production and construction effort.

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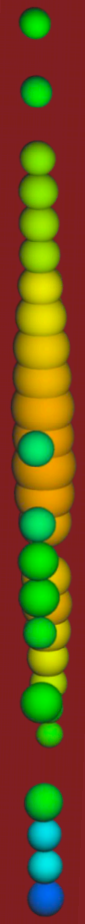
Risk



No fundamentally new technology.
Risks associated with construction are significantly less than in IceCube.

Mature IceCube-Gen2 risk register based on IceCube and IceCube Upgrade:

Technical risks being mitigated through a robust R&D program:

- Upgrade deployment of 7 strings. Includes Prototype Optical Modules for Gen2.
- Radio array RNO-G serves as R&D for Gen2. also for deployment methods.
- Large-scale production (9600 Optical Modules; 361 radio stations). Multiple production sites.
  - Upgrade production (7%) provides data.
  - Same for RNO-G (10%).
- Hot Water Drill Upgrades to support a larger spacing of IceCube-Gen2 strings. Incremental change compared to Upgrade.

- ***Cost risks*** being mitigated through early engagement of multiple vendors where possible (e.g. qualifying additional vendor(s) for photomultipliers, pressure housings.)

- ***Schedule risks*** mainly come from cargo movement uncertainties and on-ice work at the South Pole
  - Ensuring equipment is ready to enter the USAP cargo stream in time to arrive at the SP when needed– any delay in shipping equipment could mean an additional South Pole Field Season
  - Planning out on-ice work in detail; recruiting experienced drillers & detector installers; maintaining strong safety culture.

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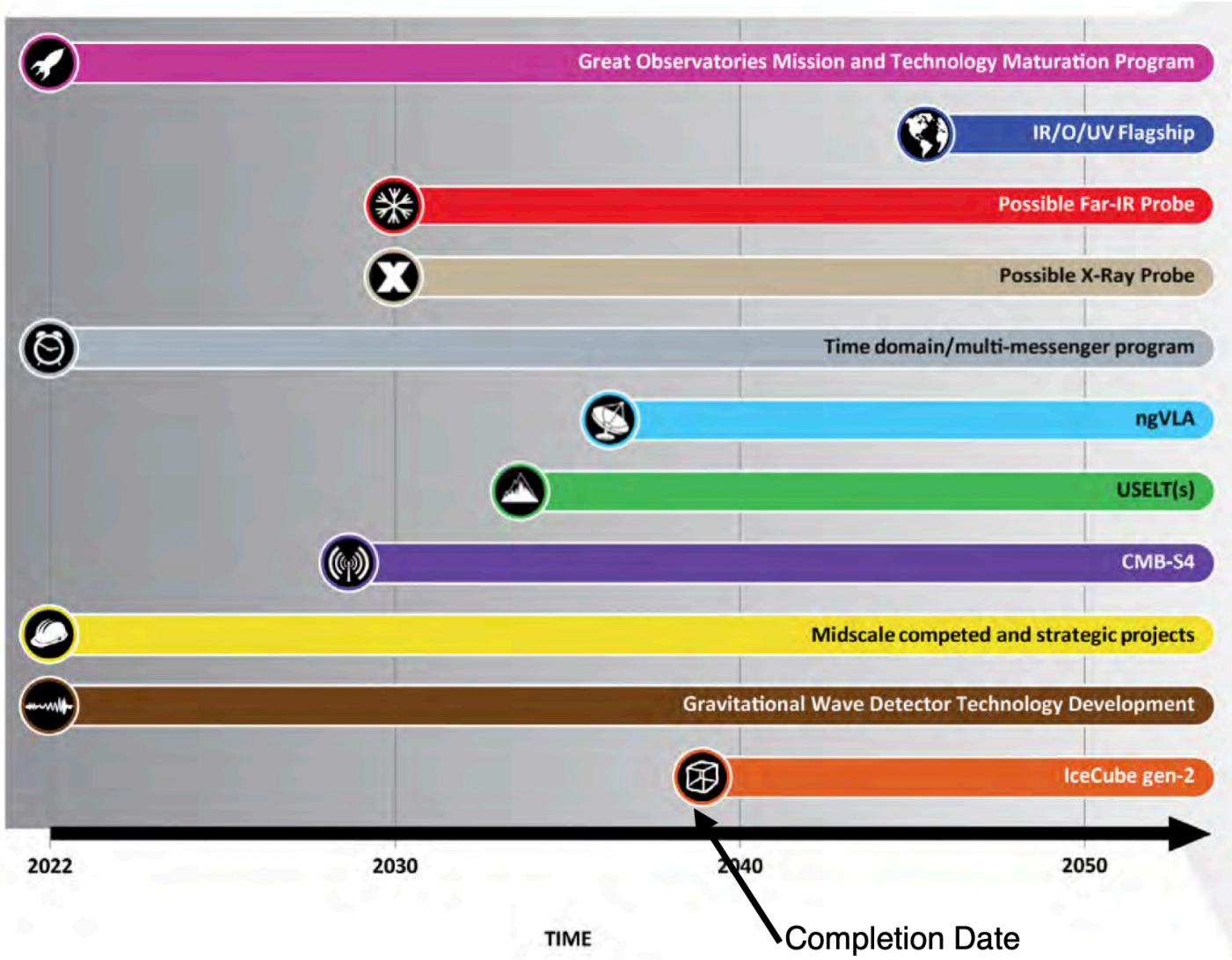
Astro 2020 US Decadal Survey,…

Gen2 was very well featured in Astro2020 US Decadal Survey.

Gen2 passed review for Helmholtz roadmap process.

From Astro2020 US Decadal Survey:
"Conclusion: The IceCube-Gen2 neutrino observatory would provide significantly enhanced capabilities for detecting high-energy neutrinos, including the ability to resolve the bright, hard-spectrum TeV-PeV neutrino background into discrete sources. **Its capabilities are important for achieving key scientific objectives of this survey.**"



IceCube GEN2

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Operations

Maintenance and Operations (M&O)

M&O at South Pole	IceCube	IceCube + Upgrade	IceCube-Gen2 (incl. IC)	IceCube-Gen2 delta
Power consumption [kW]	65	75	**190**	**115**
Population [beds]	7 – 9	7 - 9	**8 - 13**	**4**
Bandwidth [satellite, GB/day]	100	150	**300***	**150***

IceCube M&O:

21 major DAQ releases since construction. Continued improvements of ice model. Added real-time multi-messenger functionality.

IceCube-Gen2 strings to be integrated in IceCube software architecture.

Current IceCube budget (w\o analysis): ~$9M/yr (incl. $1.5M common fund)
Gen2 cost estimated 1.5 - 1.7 x IceCube ops budget.

*Bandwidth: not a hard requirement. Could design for significantly less bandwidth.

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Summary

- IceCube's **discovery of cosmic neutrinos and evidence for sources** has started a new chapter in high energy astrophysics.
- **NGC 1068**: Neutrinos are used to discover non-thermal energetic processes not seen before - in our backyard.
- **The Upgrade has been re-baselined** and is on track. The collaboration is **developing IceCube-Gen2**.
- Technical Design advanced and being documented in Technical Design Report to be released this summer.
- IceCube-Gen2 project looks forward to a **Preliminary Design Review**.

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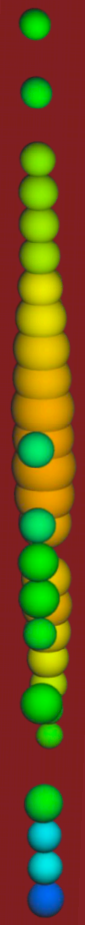
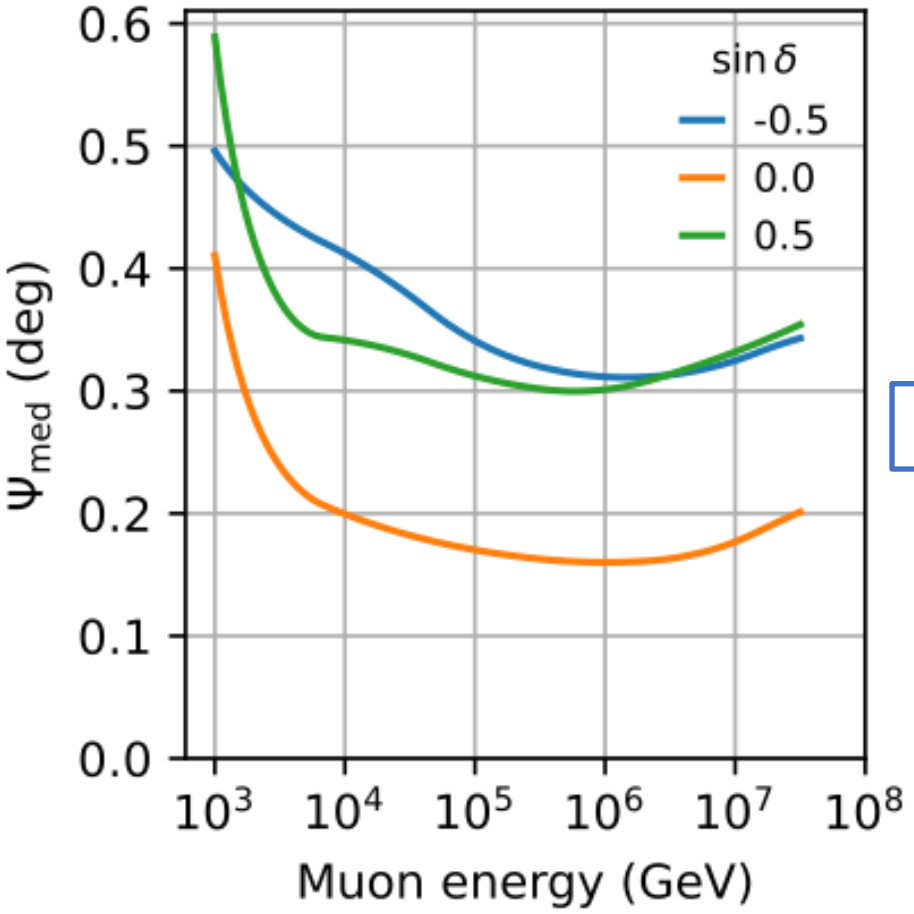
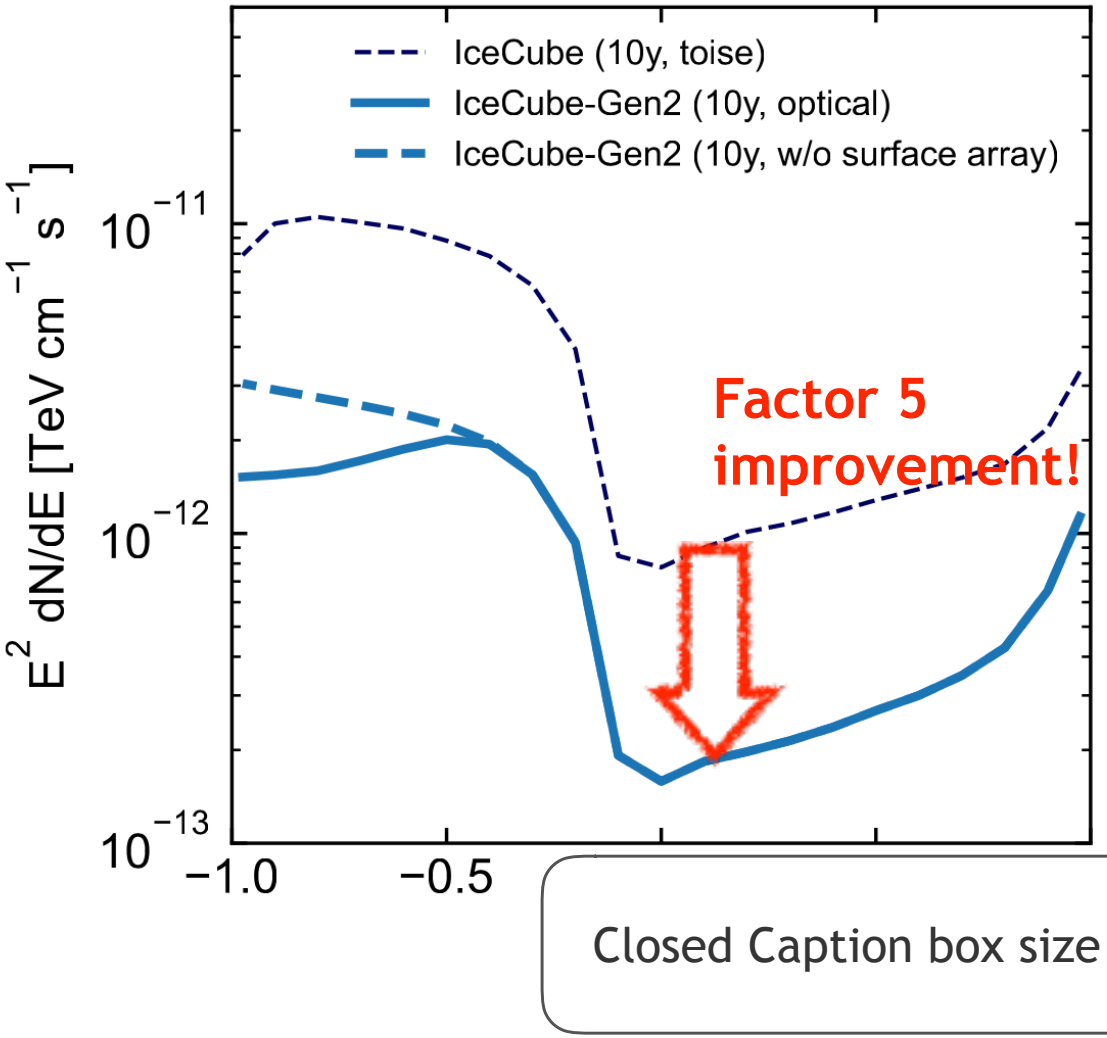


Backup

Angular resolution and sensitivity to Point Sources

Muons: 0.1 - 0.4°





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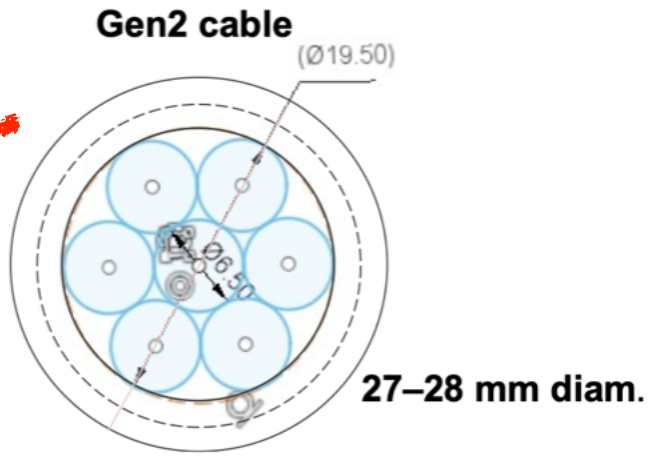
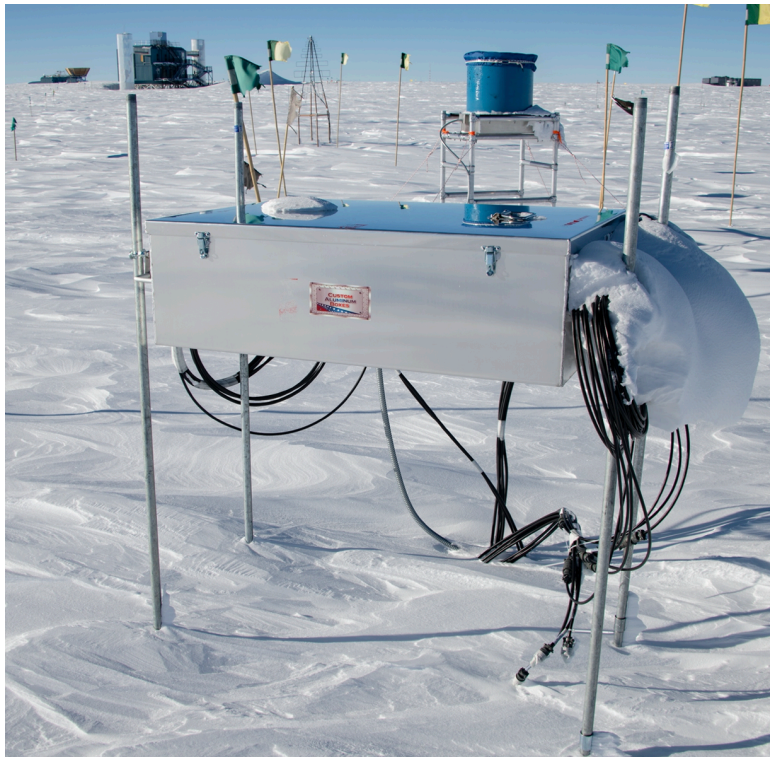
Data acquisition and cables

Upgrade cable.



Gen2 Fieldhub



IceCube: 2 DOMs/wire pair
Upgrade: 3 DOMs / wire pair
IceCube-Gen2: 6 Gen2-DOMs/wire pair (=12 x photo detection/wire pair)

This is possible due to a change in DAQ/trigger architecture:
Gen2 will not send all noise hits to the top.

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Logistical Support: Requirements

Support requirements are well understood.

South Pole Field Season	Total	Average/ year	IceCube Average
Cargo Weight [1000 lbs]	**3540**	**354**	similar
LC130 Cargo Flights	**69**	**7**	≈45
Population [beds]		**60**	≈50
Fuel [1000 gallons]	**918**	**92**	82

Absolute numbers **comparable to IceCube**.
Less than 1/5 of flights in IceCube → most cargo via Overland Traverse

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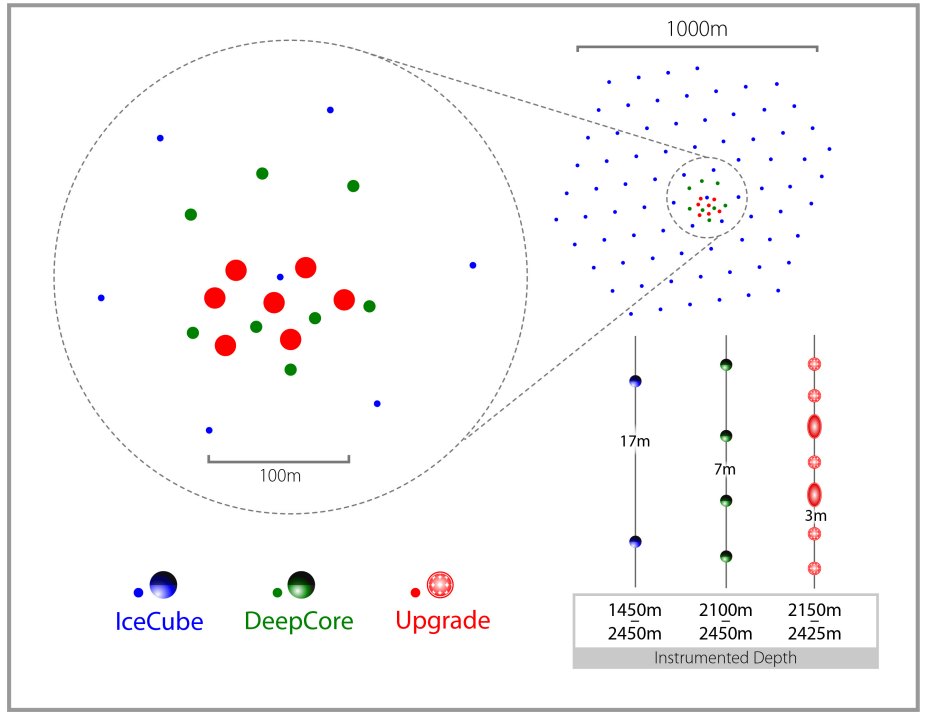
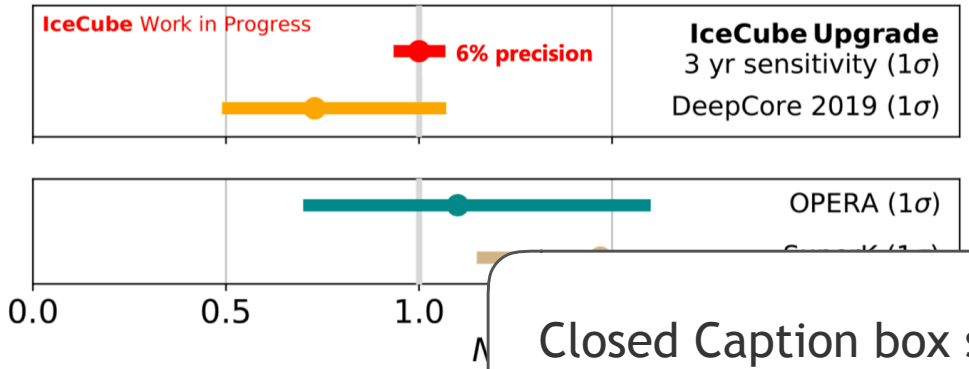


Science example:
Atmospheric tau neutrino appearance



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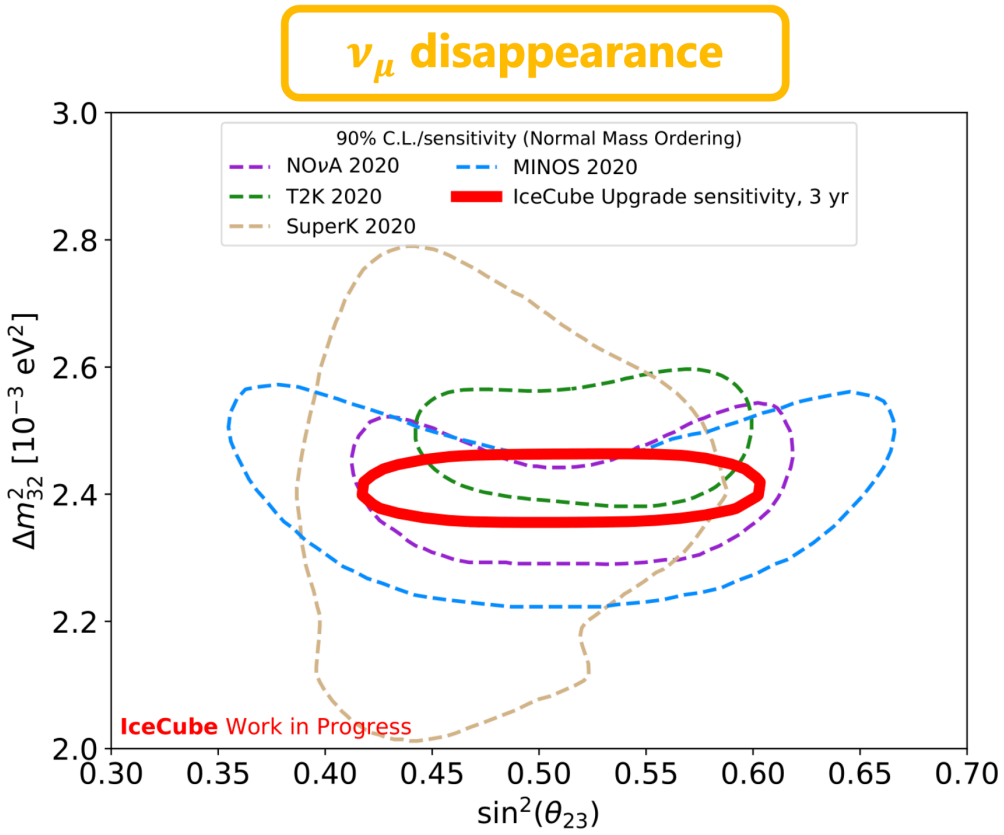
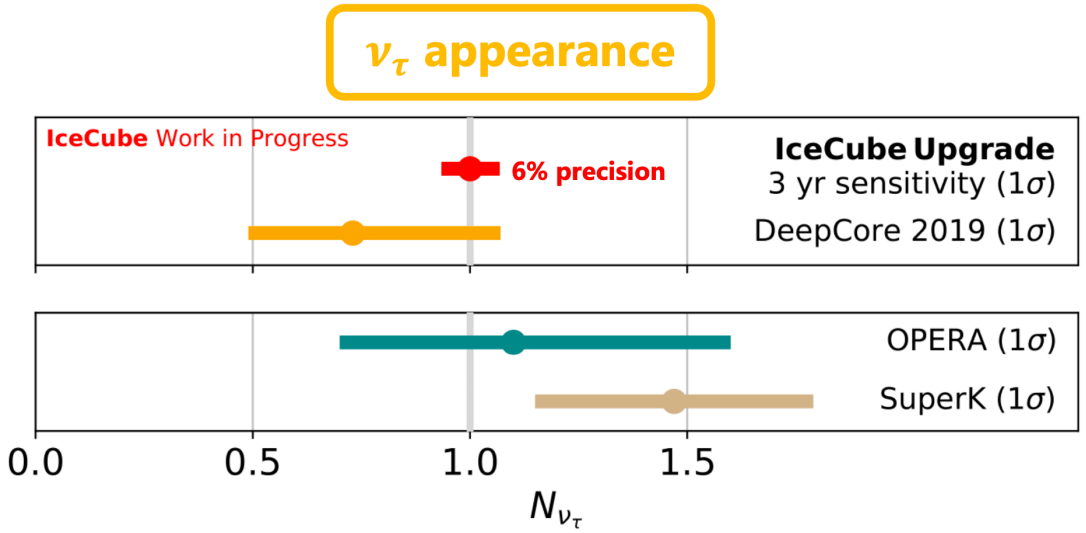
IceCube-Upgrade

IceCube Upgrade sensitivity after only 3 years





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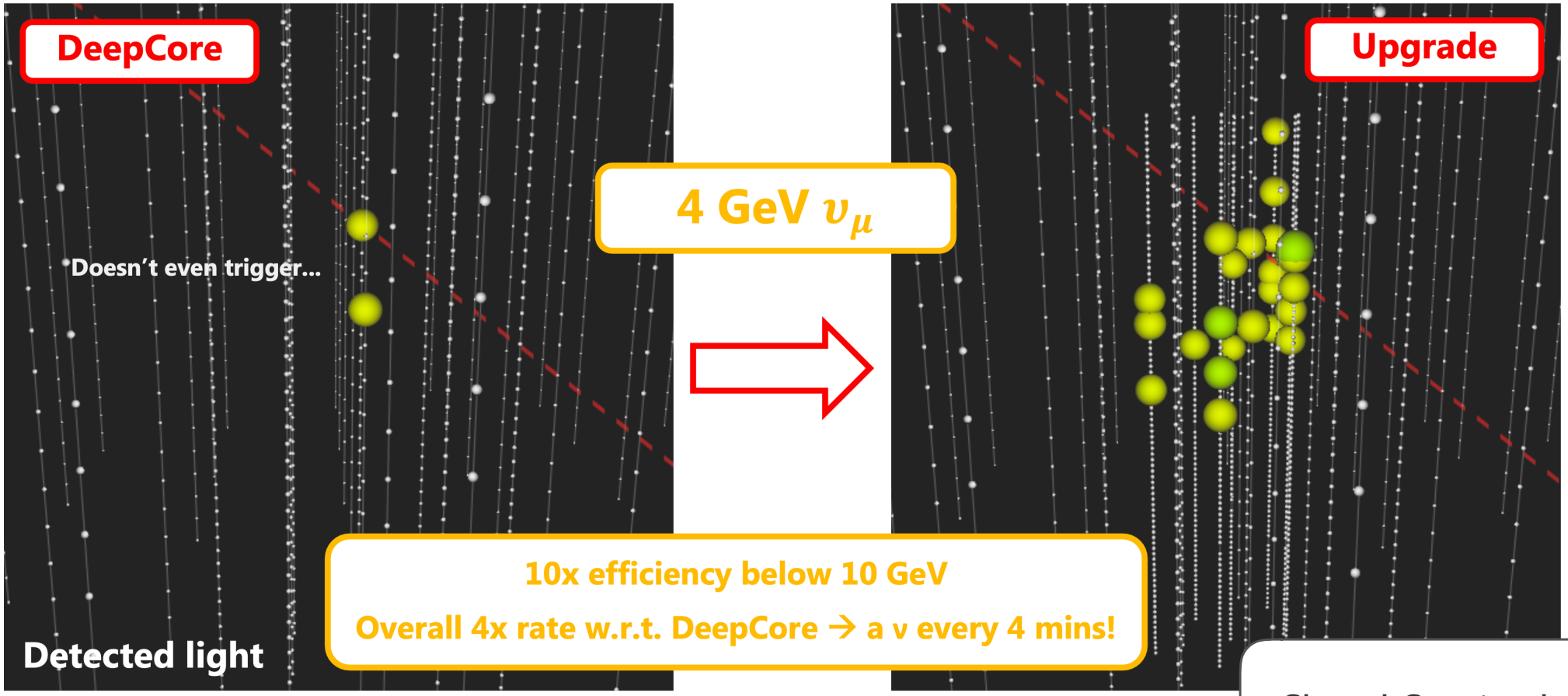
IceCube-Upgrade

Dense instrumentation in 2 Mton core

- Large increase in photocathode density → sensitive down to ~**1 GeV neutrinos**



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Global Neutrino Telescope landscape